Confinement Of Pure Ion Plasma In A Cylindrical Current Sheet

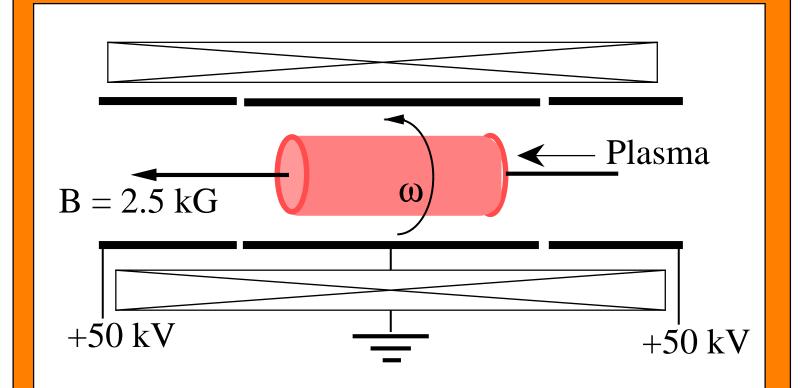
Stephen F. Paul

Plasma Physics Laboratory Princeton University Princeton, New Jersey 08543





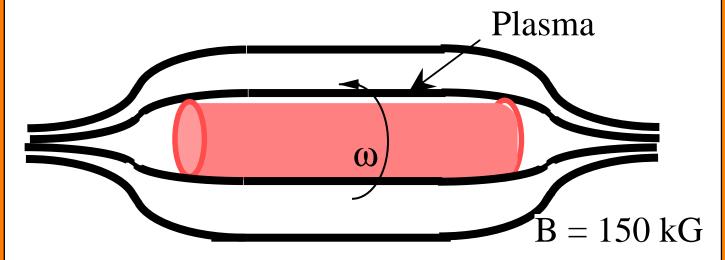
Pure Ion Current Sheet Reactor



- Start with low-density ion plasma (10¹⁰ cm⁻³) in a Malmberg -Penning Trap - uniform B
- Ramp strong mirror field: B increases outside the plasma-- does not penetrate to the interior
- Simultaneously inject ions; Space charge counteracts inward pinch to keep radius constant
- $^{\bullet}$ Hollow high-density plasma (4 \times 10 14 cm $^{-3}$) is trapped between E and B field

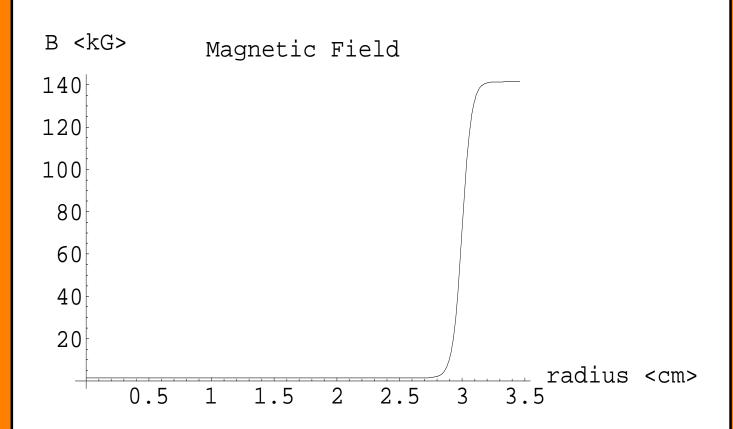
Schematic of Pure Ion Plasma Confinement

Mirror Trap with hollow cylindrical plasma in a non-uniform B-field



- Hollow plasma confined by mirror **B** field: $(M-1)\mu(\delta B/\delta z)$ opposes the eE_z; mirror ratio need be 2.85 to confine 215 MV space charge
- Very high w_{\perp} due to relativistic ($\beta=0.4$) azimuthal velocity of shell -- no plasma on axis
- Fusion products are lost: w_{\perp} of protons is inadequate to confine axially; ⁴He are lost radially when r_{L} increases

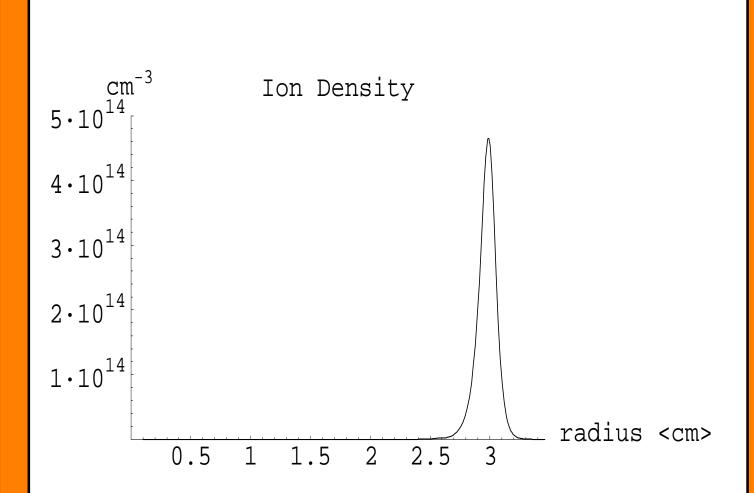
Ramp the axial magnetic field



- The ramped B-field does not penetrate the highly conducting ion plasma.
- In calculation B-field is specified.
- Parameterized by r_0 , the radius of the shell, d_0 , the penetration depth, and B_{z0} , the field strength outside the plasma.

$$B_{z}(r) = B_{z0}/2 \left\{ 1 + Tanh \left[(r^2 - r_0^2)/2/d_0^2 \right] \right\}$$
 (and $r_0 = 3$ cm, $d_0 = 0.15$ cm, $B_{z0} = 140$ kG)

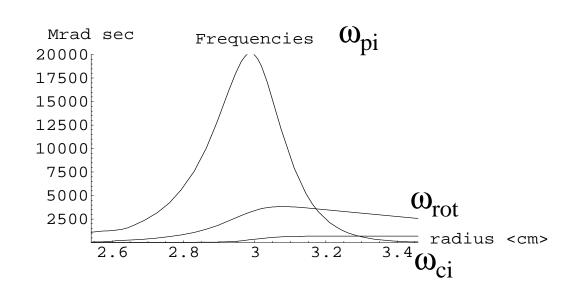
Simultaneously ionsare injected into the plasma forming a thin, high-densityshell.



Given the velocity profile, calculate density from Amperes law:

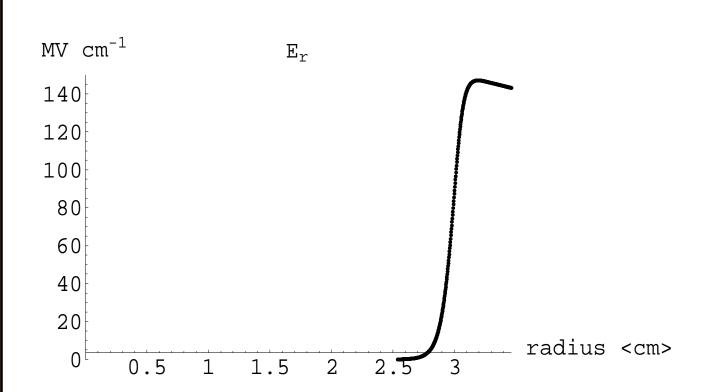
$$n(r) = \frac{dBz/dr}{4\pi e\beta(r)}$$

Equilibrium established with density much higher than Brillouin limit for a constant density plasma in uniform magnetic field



- Familiar expression for Brillouin limit: $2\omega_p^2/\omega_c^2 \le 1$ and $\omega_{rot} = \omega_c/2$
- Due to high non-uniformity of B field and peakedness of density profile, equilibrium established at $2\omega_p^2/\omega_c^2 = \underline{1600}$ and $\omega_{rot} = 6\omega_c!$
- At peak of DD cross section at 2.5 MeV, 22 kW/meter of direction conversion fusion power released--100 m long, 10 cm diameter reactor provides 2.2 MW electric.

Large space charge at surface -- but no charge or field inside.



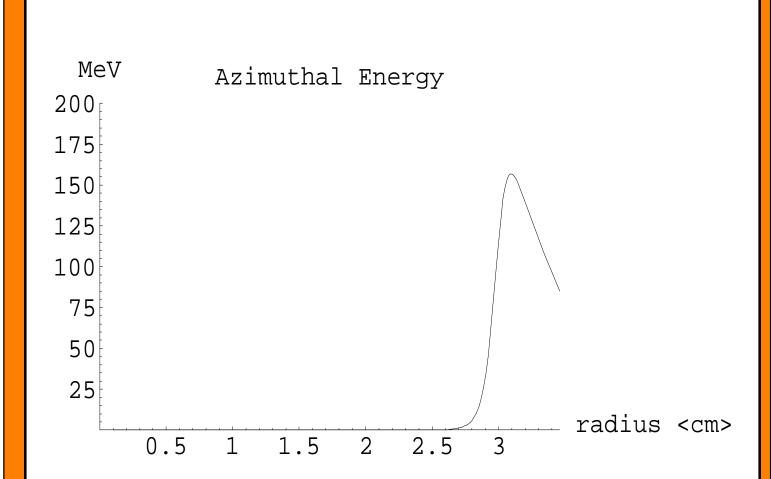
• Given the calculated density profile, obtain radial electric field from Gauss' law:

 $E(r) = 300 \times 10^6 4\pi e \int n(r')r'dr'$

r

• Intense B field magnetically shields plasma from electrons created by field emission -- electrons are not confined axially.

$E \times B$ rotation at surface accelerates deuterons to relativistic speeds (150 MV) in aximuthal direction



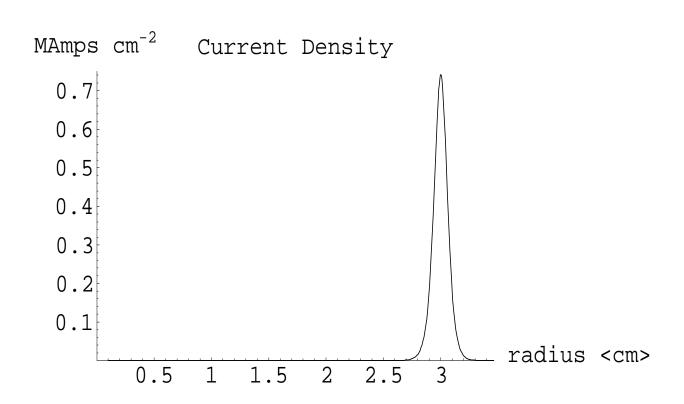
Solving the relativistic force balance equation with the given B field together with Ampere's and Gauss' Law, uniquely determines the rotation profile:

$$dB_{Z}/dr - \gamma^{2}\beta^{2}B_{Z}/r$$

$$d\beta(r)/dr = \underline{\hspace{1cm}}$$

$$\gamma^2\beta B_z + mc^2/e/r(\beta^4\gamma^5 + 2\beta^2\gamma^3)$$

Higher current density confines plasma through inward radial $J \times B$ force.



calculate current density profile from definition:

$$j(r) = n(r)e\beta(r)c$$

Next steps:

Equilibrium calculated using single component cold and warm fluid model which includes solving of Maxwell's equations, continuity and, force balance with relativistic corrections.

Next steps are to include finite temperature effects and testing for stability using a PIC simulation.